UNIVERSITY OF CALIFORNIA PUBLICATIONS
Bulletin of the Department of Geology
[illegible] pp. 17[illegible], Pl. 18. ANDREW C. LAWSON, Editor

THE IGNEOUS ROCKS NEAR PAJARO

BY

JOHN A. REID

BERKELEY
THE UNIVERSITY PRESS
NOVEMBER, 1902
PRICE 15 CENTS

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Vol. 3, No. 6, pp. 173-190, Pl. 18 ANDREW C. LAWSON, Editor

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CONTENTS.

INTRODUCTORY NOTE.

These notes are offered as a small contribution to the knowledge of the granitic rocks of the Coast Ranges of California. No attempts at the correlation of these rocks have yet been made, and the following notes are presented in the hope that they may be a start in the right direction, and of service to other workers. Several interesting and important questions have arisen, chiefly on the nomenclature of intermediate rock types of basic composition, and it is the aim of this paper to call attention to them.*

* My acknowledgments are due Professor A. C. Lawson, under whose care and advice this work was completed.

OCCURRENCE.

The rock which forms the subject of these notes is exposed at the quarry of the Granite Rock Company on the Pajaro River, about seven miles east of Pajaro station on the line of the Southern Pacific Railroad. It forms the axis of a ridge running approximately N. 35° W., through which the river has cut a gorge five hundred feet deep, the walls on both sides being composed largely of the rock under discussion. Southward along the ridge the rock can be traced on the east flank, by exposures in the gullies, for a mile; further south the overlying sedimentaries cover it completely. To the north of the river cañon no good outcrops have been found, the only indications consisting of surface wash, which contains fragments of the rock, on the west flank of the ridge. In the cañon the north wall, while presenting a few jutting outcrops, is too overgrown with heavy brush or covered with soil to allow much investigation. It is only on the south, where the quarry faces are being worked, that the rock can be well seen.

GEOLOGICAL RELATIONS.

The ridge of which this rock forms the axis is one of a series of parallel ridges composing this portion of the Coast Ranges. From the Pajaro River at the quarry, for three miles south the altitude of the hills is comparatively low, midway between the Santa Cruz Mountains on the north and the Gavilan Range on the south. For lack of a better arbitrary line dividing these two units of the California Coast Ranges, and because the igneous rock to be discussed is probably genetically connected with the granite of the Gavilan Mountains, the Pajaro River will be taken as dividing line, and all south as a portion of the Gavilan Range.

At the point of best exposure of the rock, the San Juan valley lies to the southeast, and the upper Pajaro valley to the west. The Pajaro River approaches from the southeast and flows for half a mile along the line of contact between the plutonic rock and the overlying sedimentaries. It turns then nearly at right angles directly across the ridge, and flows southwestward toward the ocean. A very sharp elbow is thus formed.

The ridge has the nature of a simple fold, with the plutonic

rock in the anticlinal axis. On either side are overlying sedimentary rocks, to the west dipping gradually under the valley soil, and to the east buckled into another similar fold. The fold next to the east, however, is exposed only as far south as the river; south of that lies the San Juan valley.

It is at the elbow of the river above mentioned, and at the railroad bridge a quarter of a mile southeast, that the nature of the overlying sedimentary rocks is best seen.

At a point a few yards east of the railroad bridge is found the synclinal axis separating the ridge mentioned from the one to the east. From this point to the elbow of the river these sedimentaries dip at angles varying from from nearly 90° to 40° to the east. They are of soft white shales, with some medium-grained yellowish sandstone near the bottom, all rather thinly bedded. On the west flank of the ridge near the quarry are found the same series, but nearly all removed by erosion. The sandstone near the base is well exposed, however, dipping 40° to the west. To the north of the quarry, on the west flank of the ridge, the transverse cañons all through the anticlinal axis and beyond the syncline already mentioned, show a well developed sequence of coarse, rather thickly bedded yellowish sandstone below, and white shales, thinly bedded, above. Three miles south of the quarry, on the road from Watsonville to San Juan, the same coarse, heavy-bedded, yellowish sandstones appear on the summit of the ridge. The road here passes through what appears to be the old worn channel of a fairly large stream, being bounded on both sides by water-worn cliffs of sandstone.

No fossils were found in this series of sandstones and shales, hence its age is somewhat uncertain. In lithological characters, however, it corresponds well with the rocks of the lower Monterey. Future research will probably show its close relation to the rocks of this series.

At the quarry, on the west slope of the ridge, is found a later overlying series of friable sandstones, non-coherent sands, and heavily bedded shales. These rocks lie across the truncated edges of the first named series and upon the worn surface of the igneous rock. The sandstone and loose sands, showing the characteristic cross bedding of beach sands, lie lowest, and are

covered by a bed of white sandy shale in a single stratum from four to ten feet in thickness. This series of rocks dips at an angle of 15° to the west. The crest of the ridge above the quarry is bare of overlying sedimentary rocks for a hundred yards back from the cañon.

The age of this second series of sandstones and shales is also uncertain, due to lack of sufficient fossils. What shells were found, however, taken in connection with the stratigraphic relations, would make the age probably late Pliocene.

The plutonic rock itself is broken and shattered in all directions, showing the great stresses and movements to which it has been subjected.

PETROGRAPHICAL TYPES.

The plutonic rock, as a mass, is of constant character, but contains both acid and basic modifications in the form of dykes and inclusions. The basic phase, consisting of a darker, finer-grained variety than the main mass, is the oldest portion of the whole, and contains intrusions of all the other phases. The acid variety occurs only in dykes, from the fraction of an inch up to a foot in width, and cuts both the other phases of the rock. However, the basic phase appears to occur chiefly in the west of the exposure, while the acid dykes are more numerous in the east. The dykes are both pegmatitic and aplitic. These four types of the rock will each be taken up in turn and discussed.

THE MAIN MASS.

Macroscopical Characters.—In a hand specimen this rock is seen to consist of black hornblende and a glassy feldspar, of about equal proportions. The hornblende shows a well developed prismatic cleavage, and a slight tendency toward idiomorphic forms. Some of the crystals are 12 mm. in length, but average about 5 mm. The feldspar is in more or less irregular grains, averaging 4 mm. in size. A few of these show cleavage faces. Besides these essential minerals there occur some small flakes, 1.5 mm. in size, of lustrous brown biotite, scattered very sparingly throughout the rock. Wherever the biotite occurs, the surrounding minerals are stained greenish, from the slight alteration of biotite to chlorite. Original pyrite also occurs in small grains.

Microscopical Characters.—Under the microscope the rock is seen to be composed essentially of light and dark green hornblende and a clear vitreous plagioclase, with a little more feldspar than amphibole. Both minerals are in smaller crystals than appears in the hand specimen, each seeming crystal being composed of several distinct smaller ones. The accessory minerals are magnetite, apatite, biotite, and pyrite, in order of relative abundance. The magnetite is in rather large amount, conspicuous under the microscope. Lastly, a little quartz occurs interstitially. The secondary minerals are chlorite, epidote, and a little limonite.

The hornblende occurs in the usual prismatic form with the faces (110) and (010) developed. The crystals average in length 3.97 mm. with a maximum cross section of .9 mm. Terminal planes are entirely lacking. There are two varieties of the minerals: a dark green, and a light green to nearly colorless. Basal sections show besides the traces of prismatic cleavage, a distinct parting parallel to (100). Longitudinal sections cut parallel or nearly parallel to (010) show also a very distinct parting on ($\bar{h}$ o l). This parting is developed best in the lighter colored hornblende. The minimum angle observed between this parting plane and the vertical crystallographic axis was 68° 54′, which would make $h = l = 1$ or the cleavage plane ($\bar{1}01$). The pleochroism is $\mathfrak{c}$ = bluish green; $\mathfrak{b}$ = olive green; $\mathfrak{a}$ = yellow. The absorbtion scheme is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The two varieties differ in color, intensity of pleochroism, and absorbtion, and the double refraction is a little stronger in the light than in the dark variety. The angle of extinction is the same for both, averaging 16°, and the direction of extinction being nearly at right angles to the transverse parting on ($\bar{1}01$). Twinning is frequent on (100), the two main divisions of a twin often showing three or four twinned lamellae between them. In sections cut parallel to (010), this twinning causes with the parting on ($\bar{1}01$) a faint "herring bone" structure similar to that shown by augite.

The two varieties of hornblende are crystallized in perfect continuity with each other. Sometimes the dark mineral is the center of a crystal; sometimes the light forms the neucleus. In general it may be said, however, that the dark green variety is

the older and probably the more basic form, as in the majority of cases the light mineral is moulded around it.

The minerals included in the hornblende are magnetite in irregular grains and well-formed crystals, and apatite in small prisms. Some secondary epidote, with its very high birefringence, has been formed, as well as some chlorite. The epidote is often interlocked with fibers of undecomposed hornblende in an intricate manner.

The feldspars under the microscope are very clear, and in most cases free from secondary products. What appears to be single crystals to the unaided eye are found to consist of a number of smaller individuals, with a few traces of idiomorphic boundaries. In size the crystals range from 3.09 mm. at a maximum to less than 1 mm., averaging 1.10 mm. Cleavages parallel to base and brachypinacoid are developed sparingly. The twinning most commonly observed is that on the albite law; often pericline lamellae are seen, and more rarely carlsbad twins. The measurement of the maximum symmetrical extinction angles on the albite lamellae indicate that the feldspars range from andesine, with an extinction angle of 20°, to a medium basic labradorite, with an extinction angle of 41°. However, most of the feldspar corresponds to an acid labradorite, with an extinction angle of 35°. This determination of the feldspars was checked by specific gravity tests, using Klein's solution. A small amount of feldspar came down at 2.64, and a somewhat larger amount at 2.65. The major portion, a little over half, came down at from 2.66 to 2.68, while the remainder did not fall until a specific gravity of 2.70 was reached. Thus the plagioclase is mostly an acid labradorite, with some basic labradorite and considerable andesine.

Zonal structure is common, the zones being usually divided by sharp lines. The most basic feldspar is at the center, and shows a greater number of twinning lamellae than the more acid border. In a few cases the change from basic to acid is a gradual one, a progessive wave of extinction crossing the crystals as the stage of the microscope is revolved. These zonal crystals show the best approach to idiomorphism, except in the cases where quartz is in contact with the feldspar. Inclusions are few,

being limited to magnetite and apatite, and secondary products are practically absent.

The biotite shows its usual characteristics. It is red-brown in basal sections, with strong pleochroism in sections perpendicular to the base, showing colors from yellow to deep brown.

The magnetite is a striking constituent of the rock, occurring in large irregular grains up to 1.01 mm. in size. Also it shows well developed crystal form in octahedra. Many of the crystals show striations which may be traces of cleavage, and a brilliantly reflecting surface of a crystal was observed in one slide. The percentage of magnetite in the rock, as extracted by the magnet, is 2.05 per cent. The apatite, in prisms .19 mm. by .045 mm. in diameter, and grains of pyrite in all sizes up to 1 mm. occur in the usual manner and need no detailed description.

The last material to crystallize is some interstitial quartz, sometimes in relatively large grain 2 mm. in size. It is not abundant, and when found, has the usual characteristics of granitic quartz. The minerals in contact with it often exhibit well developed crystal faces.

In structure the rock cames nearest to the granitic, or hypidiomorphic granular, although showing traces of porphyritic. The order of crystallization is, from first to last, magnetite, apatite, hornblende, feldspar, and quartz.

THE BASIC PHASE.

In the hand this rock appears made up of black hornblende and glassy feldspar, of a grain equal to that of a medium fine grained sandstone, the crystals being .5 mm. to 1 mm. in size The dark mineral appears in slight excess, causing the rock to show a very dark color. In the field this variety occurs in inclusions in the main mass from an inch in diameter to large irregular lens-shaped bodies many feet in diameter. These larger occurrences stand nearly vertical and are invaded by small intrusions of the main mass. Some show what appears at first glance to be a flow structure, in fine white lines of feldspar.

Under the microscope the rock is found to consist of green hornblende and plagioclase, with accessory magnetite and apatite. No quartz is present. The two essential minerals are about equal in amount, though variations occur in which horn

blende clearly predominates. The grain is fine, the hornblende averaging .31 mm in size of crystals, and the feldspar .25 mm. Very few crystal faces are developed, the rock presenting a good hypidiomorphic granular structure. That which in the hand specimen looks like flow structure is composed of rough lines of feldspar crystals somewhat larger than the average. The hornblende crystals often have a rough approximation to an allignment parallel to these feldspar bands. This would indicate that the rock was subjected to pressure when in a more or less plastic condition. The roughly lens-shaped masses of the rock would seem to indicate the same. In some portions of these bodies the rock has been fractured in parallel lines, which have become filled with secondary epidote.

In those portions of the rock which show no traces of parallel arrangement of the crystals, no decomposition products occur; in that which shows effect of pressure a little hornblende has changed to epidote and the feldspars are clouded.

The hornblende has the same characteristics as that of the main mass. The two varieties, light and dark colored, appear in the same manner. The differences are: first, a much greater tendency to twinning on (100); second, the parting on ($\bar{1}01$) is shown only in a few of the larger crystals; and lastly, no traces of a parting on (100) can be found.

The feldspars occur in crystals elongated parallel to the albite twinning lamellae. Only traces of cleavage are present. Zonal structure is found, but not well developed. The range in composition of these plagioclases is from andesine. with a maximum extinction angle of 20°, to acid labradorite, with a maximum angle of 35°. They thus correspond with the feldspar of the main mass, but are a trifle more acid. All characters are the same. The magnetite is in small grains in size up to .1 mm, scattered throughout. It often shows well developed octahedral form. In this rock phase it also shows undoubted cleavage parallel to the octahedral faces. In some of the larger grains the grinding of the rock slide has caused the appearance of a series of parallel cleavage faces, which show high metallic luster. The biotite and apatite occur in relatively small amount and do not differ from that already commented on.

THE ACID DYKES.

The two rocks already described are cut by a network of small dykes, the rocks composing which range from a fine grained aplitic type to a very coarse grained pegmatite. Intermediate types are also found, as will be discussed later.

Aplite.—In the hand this type is of fine grain, showing clear quartz, a white or pinkish cloudy feldspar, and a small amount lustrous muscovite. The quartz and feldspars appear to be in grains .7 mm. in size, and some of the muscovite flakes are 2 mm. in diameter. The mica, while normally of small amount, in some cases increases so as to make up practically all the rock. Under the microscope the rock is seen to be composed of quartz, orthoclase, microcline, plagioclase, and muscovite, with a very few ragged crystals of hornblende. A few grains of pyrrhotite occur, usually much altered to hematite. Epidote and chlorite occur secondarily derived from the hornblende.

The quartz occurs in irregular grains molded around the other constituents, and is clear and free from inclusions. It makes up about 25 per cent. of the rock. In size of grain it averages .36 mm., with a maximum of 1.46 mm. The orthoclase occurs in slightly larger crystals, elongated parallel to the clino-axis and exhibiting some very good cleavages on the base (001) and (010). The size of the crystals averages .75 mm., with a maximum of 2.95 mm. It is much decomposed, zonal structure being often well developed in the alteration. Kaolin is the chief product of decomposition, though some sericite is formed, the crystals altering from the center outward. The orthoclase often contains inclusions of flakes of muscovite, seemingly parallel to the crystallographic directions (001) and ($\bar{1}01$). Wavy extinction is frequent. The orthoclase makes up between 40 and 50 per cent. of the whole. A small amount of microcline is found, usually in smaller grains than the orthoclase, recognized by its characteristic cross-hatched structure. It crystallized out before the quartz, coincident with the orthoclase. It makes up about 5 per cent. of the rock.

The plagioclase occurs in irregular crystals, of the same size as the potash feldspar. It is twinned only on the albite law.

The maximum extinction angle measured on the albite lamellae, is 9°, which indicate that it is oligoclase. It shows less decomposition than the orthoclase, and no good cleavage. It makes up about 20 per cent. of the rock. Some traces of poikilitic structure were observed, the plagioclase being included in the orthoclase. The muscovite occurs in flakes, averaging .58 mm. in diameter, with well defined basal terminations and ragged edges. It shows the usual high interference tints and strong absorption. A little biotite sometimes occurs, in crystallographic continuity with the colorless mica. The mica makes up about 5 per cent of the rock.

The hornblende, when it occurs, is in small ragged crystals, averaging .25 mm. in size, and of the usual characteristics. It is often altered to chlorite and epidote. A few grains of magnetite are found with the hornblendes. The normal order of crystallization holds, save that the microcline crystallized before the quartz.

Pegmatite.—The other type of dyke rock is a coarse grained pegmatite, consisting, as seen in a hand specimen, of clear quartz, cloudy feldspar, and biotite. The quartz and feldspar are intimately mixed, the individual crystals of each averaging 1 cm. or a little larger, in size. The feldspars, to the naked eye, appear to be of two varieties, one being more cloudy and showing better cleavage than the other. The biotite recurs in large flakes, arranged in all directions through the rock mass. These flakes are often 5 cm. to 7 cm. in diameter. In all of this phase of the rock, taken from the zone of weathering, the biotite was almost completely altered to green chlorite, traces of the original lustrous brown mica remaining in the centers of the largest. There is often an approach to graphic structure with the quartz and the feldspar.

The type of coarse grained pegmatite passes by gradations into the fine grained aplite. The grain becomes finer, muscovite appears in small flakes, and with the disappearance of the biotite the aplitic phase is reached. A phase illustrating very well the intermediate type was found: a normal fine grained granite, with both micas well developed. Also, some varieties of the dyke rocks were found consisting of biotite and muscovite almost entirely, the whole stained green by secondary chlorite.

Under the microscope the quartz and the feldspar are seen to be intricately crystallized in interlocking grains. As with all the other rock types discussed, the grain is finer than appears in a hand specimen.

The quartz is the last mineral to separate out, occurring in large irregular crystals molded on and around the other constituents, It shows undulatory extinction and also a peculiar faint irregularly lined structure between crossed nicols that looks somewhat like an incipient cross-hatched structure of microline. This structure is no doubt due to strains in the rock. Inclusions in the quartz are few. It makes up from 30 per cent. to 50 per cent. of the rock, varying in different parts. The feldspars are orthoclase, microcline and plagioclase. These are associated in a rather complex manner, the relative proportions of each varying in different portions. The orthoclase, however, averages less than in the aplite. It shows no twinning, but cleavages on (001) and (010) are very well developed, that on the base being the better. It is somewhat decomposed into cloudy kaolin, but most of its opaque appearance is due to a great number of inclusions. These are small flakes of muscovite, with many liquid inclusions, and smaller ones that cannot be definitely determined. The orthoclase makes up about 20 per cent. of the rock. The plagioclase shows the usual albite twinning, with a few pericline lamellae. The usual optical methods show it to be oligoclase, as in the aplite. It shows less inclusions and products of decomposition than the orthoclase, with much poorer cleavage. A little calcite is formed secondarily. Checks on the determination of the feldspars were made by specific gravity tests. By Klein's solution the orthoclase, with good cleavage and very cloudy appearance, came down at 2.57, and the clearer plagioclase, with poor cleavage, at 2.63. Also microcline, with its usual characteristics is present sparingly. It appears to have crystallized before the quartz, at the same time as the orthoclase.

The biotite is almost all altered to chlorite in the freshest rock to be obtained. At a later date, when the fresh rock is exposed in the quarry face, further study may be profitable. Hornblende occurs very sparingly as an accessory in small irregular grains much altered to epidote. Its characteristics are the

same as in the main mass. Some few grains of highly refractive sphene are also seen.

RHYOLITE.

On the top of the hill above the quarry were found small scattered boulders of disintegration of a rock totally different from any seen in place in the vicinity. The occurrence was limited entirely to a few scattered pieces of the rock, which appear to be remnants of a lava which once mantled a portion of the region. There is no connection between these fragments and the plutonic rocks above described. To the unaided eye the rock is seen to be composed of phenocrysts of clear quartz, a clear feldspar, cloudy feldspar, and biotite, in a trachytic-appearing ground mass of a yellowish gray color. Under the microscope the phenocrysts, in order of relative abundance, are oligoclase, sanidine, quartz, and biotite.

The oligoclase, recognized by its small angles of extinction on on the albite lamellae, makes up about 15 per cent. of the rock. It is in well formed crystals averaging 3 mm. in size, which sometimes show a zonal structure. The sanidine occurs in larger phenocrysts sometimes 6 mm. in size. It is very glassy, and exhibits a rather poor cleavage, which distinguishes it from the quartz. It makes up about 10 per cent. of the rock. The quartz occurs rather sparingly in more or less rounded grains, averaging 2 mm. in diameter. It is free from inclusions, and makes up about 5 per cent. of the whole.

The ground mass is too finely crystalline to be resolved under the microscope into its constituents. It appears almost purely feldspathic, however. Chemical analysis, to determine the silica content, was relied upon to settle the classification of the rock. As given in the table following, the percentage of silica is 74.12. It is therefore a rhyolite.

CHEMICAL CHARACTERISTICS.

Following is a table containing complete and partial analyses of the rocks described in these notes, with a number of similar ones for purposes of comparison:

TABLE I.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
SiO_2	49.26	46.23	53.00	48.90	52.00	55.80	56.52	49.15	45.11	46.85	74.95	74.44	74.12
TiO_2	trace	trace	.57	.26	—	.88	.25	.18	.21	.30	—	—	—
Al_2O_3	16.88	18.29	17.19	16.03	15.75	17.44	16.31	21.90	19.67	20.02	—	—	—
Fe_2O_3	6.49	* 6.55	4.78	12.52	3.55	2.59	4.28	6.60	4.32	2.30	—	—	—
FeO	6.94	* 7.07	5.05	1.12	12.84	4.67	5.92	4.54	8.57	4.60	—	—	—
CaO	7.58	9.99	8.08	8.22	7.39	7.13	6.94	8.22	10.45	13.84	—	—	—
MgO	4.80	7.04	4.66	6.24	3.42	3.59	4.32	3.03	5.65	10.16	—	—	—
MnO	.61	.12	trace	.04	—	.11	.14	—	—	trace	—	—	—
$NiO+CoO$	.05	trace	—	—	—	—	—	—	—	—	—	—	—
Na_2O	3.41	* 3.07	2.92	3.87	3.37	3.67	3.43	3.83	3.87	1.32	—	—	—
K_2O	.72	* .79	1.49	1.17	1.24	2.26	1.44	1.61	.64	trace	—	—	—
SrO	trace	trace	—	—	—	.09	—	—	—	—	—	—	—
ZrO	none	—	—	—	—	—	—	—	—	—	—	—	—
BaO	none	—	—	—	—	trace	—	—	—	—	—	—	—
P_2O_5	.34	* .21	.37	—	1.06	.33	.40	.33	.25	trace	—	—	—
H_2O—110°	.41	.05	1.35	1.66	.35	1.13	1.03	1.92	.83	.88	—	—	—
$H_2O+110°$	2.90	1.02									—	—	—
S	trace	trace	—	—	—	—	—	—	—	—	—	—	—
CO_2	undet.	—	—	—	.11	—	—	—	—	—	—	—	—
Total	100.39	*100.43	99.46	100.03	100.02	99.88	100.98	101.31	100.07	100.27	—	—	—
Sp. Gr.	2.95	2.98	2.856	2.95					2.865				

*Approx. not checked.

I. Diorite, with some quartz. Pajaro. Reid analyst.
II. Diorite, fine grained. " " "
III. Diorite, Schwarzenberg, Rosenbusch "Gesteinslehre."
IV. Diorite, " hornblende-rich. "
V. Augite diorite, Duluth, A. Streng and J. H. Kloos, "Crystalline Rocks of Minnesota," Neues Jahrbuch, 1877.
VI. Average of analyses of diorites, Pirsson, "Geol. of Little Belt Mts." U. S. G. S. 20th An. Report.
VII. Average of 14 analyses of diorites, Brögger, "Schrifter u.i Vid i. Christ." 1895.
VIII. Hornblende-gabbro, Duluth, A. Streng and J. H. Kloos, "Crystalline Rocks of Minnesota," Neues Jahrbuch, 1877.
IX. Hornblende-gabbro, Lindenfels, Odenwald, Rosenbusch, "Gesteinslehre."
X. Gabbro-diorite. Maryland. G. H. Williams.
XI. Pegmatite. Pajaro. Reid anal.
XII. Aplite. " " "
XIII. Rhyolite. " " "

In Table I, column I gives the analysis of the rock which constitutes the main mass at Pajaro. It is lower in silica and higher in iron than the average diorites. Column II gives the analysis of the finer grained, more basic phase at Pajaro. It is still lower in silica, and higher in iron, lime, and magnesia than the typical diorites. The alkalies show but little change, too small to be of importance. Columns XI, XII, and XIII give the silica contents of the pegmatite, aplite, and rhyolite, respectively. The great difference between the acidity of the dyke rocks and their inclosing rocks is at once apparent. The other columns give analyses of similar rocks taken for purposes of comparison in the discussion of nomenclature.

The following Table II gives the calculated mineral composition of analyses 1 and 2 above. The feldspars are calculated as Ab_1An_1.

Table II.

	I	II
Hornblende	55.59	58.80
Plagioclase	39.96	38.82
Magnetite	2.65	2.40
Apatite	1.14	.58
Quartz	.66	none
Total	100.00	100.00

NOMENCLATURE.

General Discussion.—In regard to the nomenclature of these rocks the question of their exact classification naturally arises. Unfortunately, it is yet impossible to assign the igneous rocks to their proper place on but one basis; there is still a clash between the purely mineralogical basis of classification and the purely chemical.

Chemically, the two principal rocks discussed in these notes may be either diorites or gabbros; and II is much nearer a typical gabbro in composition. In Table I is given an average analysis of diorites by Pirsson, column VI, and another by Brögger, in column VII. That of Brögger comes nearest representing a typical diorite. In comparison, it is seen that in VII the silica is considerably higher, while the iron, lime, and magnesia, are lower, than in I and II, II being decidedly more basic. The soda is approximately the same, but the potash is higher in VII, due to some orthoclase being present. Most of the potash belongs with the ferro-magnesian minerals, however. Columns VIII and IX give two anylyses of hornblende-gabbros. Of these, the silica is lower, and the lime and magnesia higher, than in the diorites already cited, VI and VII. The alumina is also higher in the hornblende-gabbros, and the alkalies are about the same. These two rocks are, therefore, decidedly more basic than the diorites. Column X, the gabbro-diorite of Williams, may be taken as a gabroitic rock. On comparing it with II, the more basic of the Pajaro rocks, the main differences are the higher silica, alumina, lime and magnesia, and the lower iron and alkalies; II, therefore, is a little more acid than X. Comparing II with VIII and IX again, it may be seen that II has a lower alumina content, yet on the whole is more basic. As regards I, it is more acid than these gabroitic rocks cited, but corresponds well with analysis IV, a hornblende rich diorite cited by Rosenbusch. Both I and IV are more basic than the typical diorites. Chemically, therefore, I stands intermediate between the diorites and gabbros, while II takes its place with the gabbros.

Mineralogically, the Pajaro rocks, I and II, are unequivocally diorites, being composed of hornblende and a medium basic

plagioclase. By all the tests this plagioclase is found to be an acid labradorite or basic andesine. I, while chemically more acid than II, is slightly more basic mineralogically, as it contains a small amount of basic labradorite. The conflict is apparent.

Rock I may be classified without much hesitation as a basic diorite, poor in feldspar, rich in hornblende, and with a very little quartz. This corresponds to the nomenclature of Rosenbusch, as cited in analysis IV. Rock II cannot be so easily disposed of, however, although so similar to I. Such names as hornblende-gabbro, gabbro-diorite, or diorite-gabbro naturally suggest themselves. But in the two cases cited, the term hornblende-gabbro is used to denote rocks containing hornblende as a primary constituent, with augite or diallage and a basic labradorite. Irving* uses the same term to denote a rock with basaltic hornblende, augite, diallage, labradorite essentially, and some accessory biotite, oligoclase, and quartz. This use of the term seems well taken; it should be limited to such rocks. The term gabbro-diorite, as used by Williams, analysis X, denotes a gabbro in which the original pyroxene has been changed to amphibole. In this case the term diorite-gabbro would appear to be better. Brögger has suggested the terms diorite-gabbro and gabbro-diorite for these rocks of intermediate type, but inclines more to the purely chemical differences.

Chemically II could be well placed as a diorite-gabbro, in the use of which term the latter part denotes the type nearest to which the rock approaches. Mineralogically, however, as no trace of a pyroxene exists, the hornblende being all undoubtedly primary and the feldspar an acid labradorite, the use of such a term as diorite-gabbro is not justified. Nor would gabbro-diorite be fully applicable. These two terms should be limited in use to rocks of intermediate mineralogical composition as well as chemical, else no approach to uniformity can ever be reached. Rock II has differentiated on a line not yet covered by proper names. Hence it will also be designated by the simple term diorite, as I, and of very basic composition.

Graphic Representation.—All the analyses of dioritic rocks of Table I, except V, have been plotted in the figure, Plate 18.†

* "Copper-bearing Rocks of Lake Superior." U. S. Geol. Surv. Monograph V.
† Suggested by Dr. A. C. Lawson.

In this triangulation method an equilateral triangle is divided each way into one hundred parts, each division being thus taken as a graphical representation of one per cent. The triangle is not shown in its entirety, as all the plots fall in the lower right-hand corner. The SiO_2 is set off first from the left leg of the triangle and marked on the right leg, making the apex of a new triangle whose altitude is a measure of the acidity or basicity of the rock. The second part of the plot is located by the use of the alumina and total iron percentages, as follows: The alumina content is set off to the right from the left leg of the new triangle, and the total iron is set off from the right leg to the left. The intersection of these two lines gives the second point of the plot. By connecting the two points found by a line the first segment of the plot is found. The second and third points are found in a similar manner, using the lime-magnesia and soda-potassa percentages, respectively. By joining these points by straight lines the plot is completed.

From each point found as above a triangle may be drawn, whose altitude is a measure of the content of the oxides whose lines fall within it. For instance, from the silica point a triangle may be drawn whose altitude measures the total content of the oxide in the rock, and inversely measures the acidity. From the second, the alumina-iron point, a triangle may be drawn whose altitude expresses the content of the lime, magnesia, soda, and potash, and a comparison of this with the first altitude gives the relative proportion of alumina and iron to silica. Similarly the other points serve as the apices of triangles whose altitudes express relative proportions of the different oxides. Also the length of the different segments is a similar measure, and the direction of each indicates the relative abundance of the two oxides whose content determine it.

Each plot thus consists of four points and three segments, which may or may not be calculated on a water-free basis. For the series of igneous rocks, or better, rock magmas, the plots of the basic occupy the left or center of the triangle, while the acid occupy the right. The method is yet not all to be desired, nor fully worked out in all its possibilities, still the plots serve well to bring out the likenesses and differences of the rocks cited.

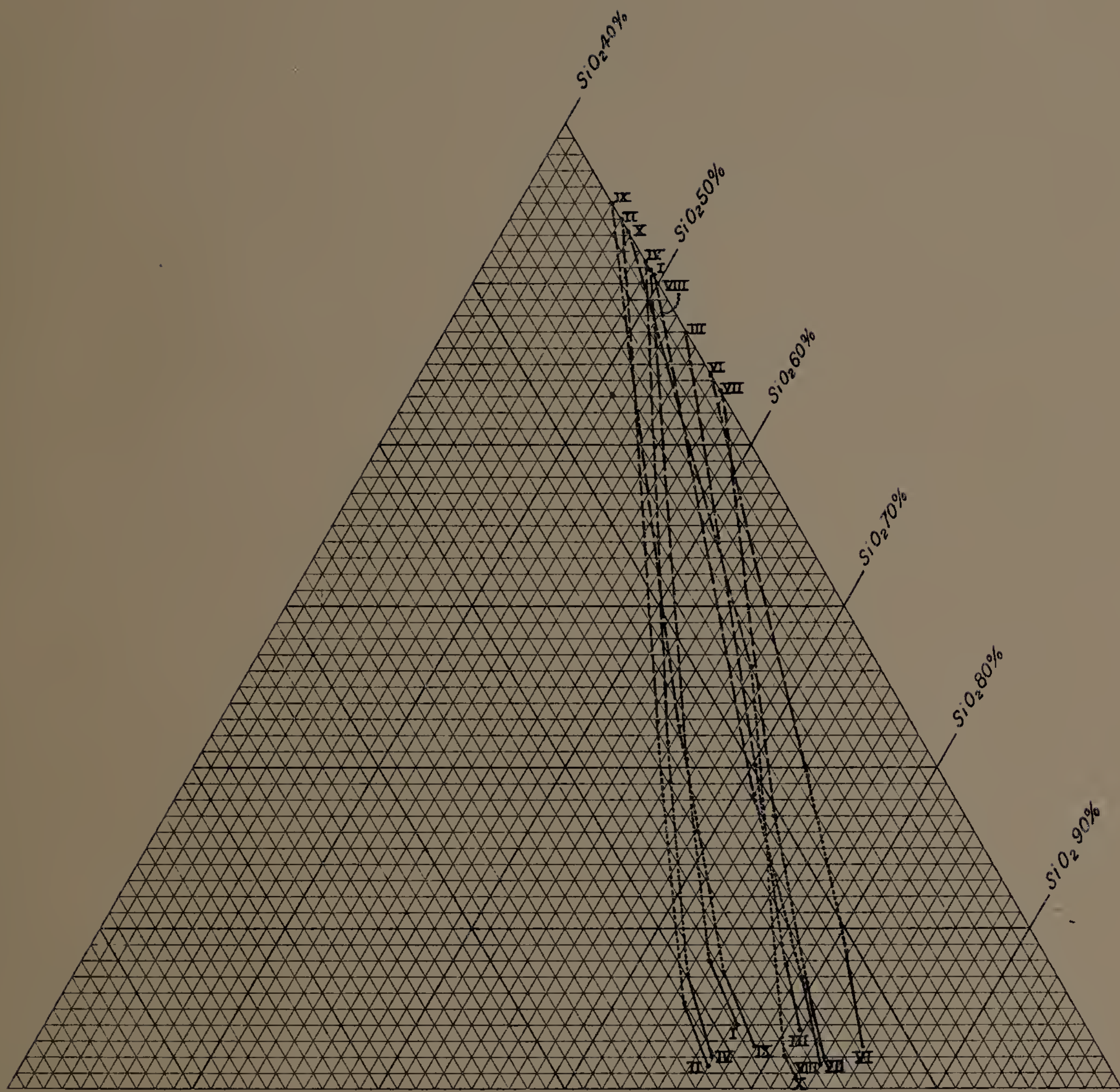
From a comparison of the nine plots, numbered in accordance with Table I, it is seen, first, that the normal diorites are more acid than the two main rocks of these notes. This is shown by the plots of the diorites being farthest to the right, their shorter Al-Fe line, Ca-Mg line, and little longer Na-K line. Second, the rocks I and II show undoubted similarity to the hornblende-gabbros, the Al-Fe line only being a trifle shorter, and to the diorite IV of Rosenbusch, a rock rich in hornblende. Thirdly, the gabbro (gabbro-diorite of Williams), analysis X, shows more basic than all, although poorer in iron. Therefore, from these plots, it appears that from the point of view of composition of igneous magmas, the Pajaro rocks are nearer the gabbros than the diorites.

CONCLUSION.

The igneous rocks at Pajaro represent a good example of the differentiation of igneous magmas. The oldest phase, the fine grained diorite, is the most basic—an ultra-basic diorite. The next in point of age is the main mass of the rock, also a basic diorite. In this phase, the change from the crystallization of the basic minerals to the acid was sudden, as is attested by the sharply zoned feldspars and little interstitial quartz. Through these two rocks were later intruded acid dykes of pegmatite and aplite, high in silica and the alkalies, often containing 50 per cent. orthoclase.

The dioritic rocks had best be called basic diorites, the great balance of their characteristics falling on that side. Their actual nomenclature has, however, disclosed the lack of conformity in rock classification, and it is to be hoped that these notes may be of some small service in calling more careful attention to the general question of the nomenclature of the more basic igneous plutonic rocks.

University of California,
May, 1902.



DIAGRAMATIC COMPARISON OF ANALYSES

Spaces.. = 1 per cent.

Al_2O_3 — $FeO + Fe_2O_3$ ———————

CaO — MgO ....

Na_2O — K_2O ————————

Percentage of SiO_2 indicated by position of initial point of curve on right side of triangle.

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VOLUME 3.